

<b>Institution:</b> Aston University
<b>Unit of Assessment:</b> 15: General Engineering
<b>Title of case study:</b> Power and chemicals from renewable sources, waste and residues
<p><b>1. Summary of the impact</b></p> <p>The impacts from over 20 years bioenergy research at Aston University, have been through influence and support for businesses to generate and use environmentally advantageous sources of power, fuels and chemicals. Pilot scale systems that exploit pyrolysis and gasification of biomass residues and renewable feed-stocks are operational. The EU, UK and local governments have developed policies with the Unit's advice on the potential of bioenergy for power generation and waste reduction. Technical and business advice have been provided, a new company formed, investments made in new business directions by SMEs and large multinational companies. This has generated new employment opportunities in consultancy, design and manufacture of systems, social and environmental benefits, along with greater public awareness.</p>
<p><b>2. Underpinning research</b></p> <p>Bioenergy was pioneered at Aston University by Prof Bridgwater well before 1993, with research in thermochemical conversion of biomass and development of controlled chemical engineering processes for generation of chemicals, fuels and energy. Pyrolysis reactors have been designed, modelled and built, at laboratory to pilot scale, for different biomass feedstocks and for the formation of specific products. Technical evaluations have been complemented by technoeconomic assessments of the effectiveness of different scenarios. The impacts from the research are timely and relevant, fully supporting environmental policies for secure supplies of green energy and waste reduction, eg European Renewable Energy Directive (2009).</p> <p>Central to the research has been the evaluation of sources of biomass for the product required. Initially, specific crops were assessed for the quality of bio-oil produced, including commercially important factors such as their stability and yield etc [eg 3.1]. With increasing recognition of the potential conflict in using agricultural land for production of food and energy crops, various high volume agricultural, domestic and industrial wastes and residues have been evaluated in collaboration with companies in these sectors, including paper mills (Aylesford Newsprint), brewery residues (Johnson Matthey with Molson Coors Brewery) and sewage sludge (Severn Trent Water). The research has shown that, through pyrolysis, biomass and residues can be used to produce power, fuels and chemicals but that careful control of feedstocks and process conditions is required to limit corrosion, minimise build-up of tar residues and to optimise physical and chemical properties of products [eg 3.2, 3.3].</p> <p>Hornung and Apfelbacher designed and patented [3.4] a system that balances both efficiency and performance to produce power. This system, an intermediate pyrolysis reactor (Pyroformer™), has treated a variety of biomass feedstocks including (uniquely) mixed wastes such as those from manufacturing processes. It produces pyrolysis oil that, when blended with biodiesel drives liquid-fuelled combined heat and power engines, and in combination with a gasifier produces a consistent gaseous fuel (hydrogen and methane). A pilot-scale Pyroformer, installed by Aston on the Harper Adams University estate, demonstrated the use of agricultural, other bioresidues and waste products to generate heat and power cost-effectively during 2012, with residual char used for land improvement - a carbon negative process. The Pyroformer won "<b>Best Technological Breakthrough</b>" category at the national Climate Week Awards held at the House of Commons in March 2013.</p> <p>Technoeconomic evaluations have demonstrated the locations and scale where bioenergy generation has greatest potential by minimising costs and maximising performance, balancing for example, transport costs of the feedstocks to pyrolysis plant with those of the products to consumers. Initial studies [3.5] have been followed by detailed analyses [eg 3.6] and form part of the information that is particularly relevant for stakeholders in bioenergy supply chains.</p> <p><b>Key researchers</b> involved in bioenergy research in the Unit have included: <b>A.V.Bridgwater</b> (Reader 1987, Prof since 1996), <b>A.Hornung</b> (Prof since 2007), <b>J.Brammer</b> Reactor design, energy system analysis, (PhD 2001, RA 2001-2002, Lecturer 2002-2013, Senior Lecturer from 2013), <b>P.A.Davies</b> Engine testing of fuels (Lecturer 2005, Senior Lecturer 2008, Reader from 2011), <b>J.Elgy</b> Biomass assessment (Lecturer 1986-present), <b>Y.Makkawi</b> Gasification, modelling (Lecturer 2008, Senior lecturer since 2013), <b>G.Griffiths</b> Oils analysis, algae (Lecturer 2005-present), <b>J.Titiloye</b> Catalysis (Lecturer 2001-13), <b>A.Apfelbacher</b> Reactors (RA 2008-12), <b>D.Nowakowski</b> Analysis (RF 2008-present), <b>A.J.Toft</b> (PhD 1996), <b>J.G.Rogers</b> (PhD 2009),</p>

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**R.Fahmi** (PhD 2008), **M.Ouadi** (PhD 2012), **J.Samanya** (PhD 2013), **Y.Yang** (current PhD student), with other RAs, RFs, PhD students and collaborators.

### 3. References to the research (the best indicators of research quality are marked \*)

The references below are a small, indicative subset of a large body of published work in this area spanning over 20 years.

- \*1. Fahmi, R., Bridgwater, A.V., Donnison, I., Yates, N. and Jones, J.M., *"The effect of lignin and inorganic species in biomass on pyrolysis oil yields, quality and stability"*, Fuel, Volume 87, Issue 7, June 2008, pages 1230-1240 doi.org/10.1016/j.fuel.2007.07.026
- \*2. Yang, Y., Brammer, J.G., Ouadi, M., Samanya, J., Hornung, A., Xu, H.M. and Li, Y., *"Characterisation of waste derived intermediate pyrolysis oils for use as diesel engine fuels"*, Fuel, Volume 103, January 2013, pages 247–257 <http://dx.doi.org/10.1016/j.fuel.2012.07.014>
- \*3. Ouadi, M., Brammer, J.G., Kay, M. and Hornung, A., *"Fixed bed downdraft gasification of paper industry wastes"*, Applied Energy, Volume 103, March 2013, pages 692–699, doi.org/10.1016/j.apenergy.2012.10.038
- 4. Hornung, A. and Apfelbacher, A., International Patent: WO 2009/138757 *"Thermal treatment of biomass"*, Publication Date: 19.11.2009 <http://www.google.com/patents/WO2009138757A2>
- 5. Bridgwater, A.V., Toft, A.J. and Brammer J.G., *"A techno-economic comparison of power production by biomass fast pyrolysis with gasification and combustion"*, Sustainable and Renewable Energy Reviews, 6 (3) pages 181-248, 2002, [http://dx.doi.org/10.1016/S1364-0321\(01\)00010-7](http://dx.doi.org/10.1016/S1364-0321(01)00010-7)
- 6. Rogers, J.G. and Brammer, J.G., *"Analysis of transport costs for energy crops for use in biomass pyrolysis plant networks"*, Biomass and Bioenergy, 33, 10, 2009, pages 1367–1375 <http://dx.doi.org/10.1016/j.biombioe.2009.05.018>

#### Key grants relevant to this case include:

- RCUK SUPERGEN *"Bioenergy"*, 3 phases totalling £10M, (2003-2017) A.Bridgwater
- AWM ERDF project *"Bioenergy Research and Industrial Development in the West Midlands"*, £7,153k, R.F.Berry (Dean, School of Engineering and Applied Science) (2011-2015)
- RCUK Science Bridge *"Technology and Business Solutions for the UK and India"*, £1.5M (2009-12) P.Davies
- EPSRC CASE / Severn Trent Water Ltd – *"To develop efficient methods to turn sewage sludge into heat and electricity"* £86,789 (2009-12) A.Hornung
- EPSRC CASE / Pira International Ltd *"The generation of CHP by the gasification of paper industry wastes"* £85k (2009-12) J.Brammer
- EPSRC CASE / Johnson Matthey plc *"The application of platinum group metal catalysis to thermochemical biomass processing"* £87k (2010-13) A.Hornung
- EU InterReg IVB NWE BioenNW *"Delivering local bioenergy to NW Europe"* £1,071k (2011-2015) A.Hornung

**Awards** - Aston bioenergy research was recognised most notably in the Don Klass Award at **tcbiomass** conference, Chicago (2009), and the Johannes Linneborn Prize at 15th European Bioenergy Conference (2007), both to Bridgwater for his outstanding contributions.

### 4. Details of the impact

The Unit has achieved impacts internationally from the breadth of its bioenergy research through projects, demonstrations, advice and consultancy, for governments, companies, communities and charity work. The **routes to create impacts** have increasingly been through the European Bioenergy Research Institute (EBRI) formed in 2008. A commercially focused knowledge transfer team, formed within EBRI in 2011, includes specialists from Aston Business School (Prof P Dey and RAs), external partners and industrial collaborators. EBRI is located in a purpose designed and constructed, facility on campus, funded by Aston and ERDF. The self-sufficient building, completed at the end 2012, incorporates research laboratories and facilities for demonstration and pilot-scale trials by companies. The expenditure of £16M on construction of the EBRI facility itself, had major business benefits for specialist engineering design and construction companies and their employees, and the building is designed to contribute significantly to the University's Carbon Management Plans.

**Impacts internationally on public policy and understanding, standards and the environment**

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The following are examples, drawing on the breadth and depth of the bioenergy research:

- *“Sustainable biofuels: prospects and challenges”*: Bridgwater was one of seven members of the Working Group that produced this independent report for the Royal Society (2008). Copies were sent to over 300 key contacts including leading figures in transport, academia, NGOs and industry, as well as UK, EU and international policy makers. Initial print run was 1500 with electronic copies also available on the Royal Society website. The report led to extensive **public debate** in mainstream international news, professional media, and other fora (over 80 high profile citations were recorded by the Royal Society in the first week [5.A]).
- Bridgwater provided expert advice to the Carbon Trust; in 2008 this led to the creation of the Pyrolysis Challenge [5.B] with £20M funding supported by UK Government, to transfer academic research into companies. Antzela Fivga (PhD 2011) was subsequently employed by one of the Carbon Trust Pyrolysis Challenge award companies, Future Blends Ltd, to use his expertise directly for plastics pyrolysis.
- *“Biomass Pyrolysis-A guide to UK Capabilities”* (2011) **International Energy Agency (IEA)**, Bioenergy Task 34 (Pyrolysis). Bridgwater led the team that compiled this guide. The Foreword by Prof David Mackay, Chief Scientific Advisor at the **Department of Energy and Climate Change**, stated *“Guides such as this help to build that awareness, and help guide research, innovation, and investment, as we work out our pathway to a secure, low-carbon energy system”* [5.C].
- Further recommendations by the IEA team, led to **International Standards** for biofuels “Standard Specification for Pyrolysis Liquid Biofuel” ASTM D7544-12, and “Standard Test Method for Pyrolysis Solids Content in Pyrolysis Liquids by Filtration of Solids in Methanol” ASTM D7579-09(2013). Bridgwater contributed expertise on evaluating biofuels composition and effectiveness.
- *“Bioenergy Technology Innovation Needs Assessment (TINA)”* Bioenergy Report, (2012). *“Bridgwater played a key role as an academic expert contributor and the TINA is now being used to develop programmes across major public sector backed organisations that are supporting low carbon innovation, through the Government **Low Carbon Innovation Coordination Group**”* [5.B].
- In recognition of the impact of their work, both Bridgwater and Hornung have been appointed by Sustainability West Midlands as **“Green Leaders”**; positions through which they are invited to develop new solutions and influence policy, act as leaders so share and pass on their experiences, skills and knowledge to companies, organisations and the public.
- EBRI is used for **promotion** of bioenergy; including a visit by The Princess Royal (2012), MPs, MEPs, international Government representatives, the media, businesses and general public; there have been 41 press releases since its launch (2008-July2013) and 69 other media (international press – BBC, ITV, Sangat TV) and public briefings between January 2012 and July 2013.

#### **Economic impacts and associated societal benefits, worldwide**

From the start of the ERDF project in 2011 (to July 2013), more than 100 companies have benefitted from presentations and individual 2-day “assistance” sessions drawing from distinct aspects of the research [5.D]. Companies include manufacturers with wastes and residues, waste contractors, land and estate developers, and pyrolysis equipment manufacturers. Of these, 85 partners (two thirds being SMEs) benefit by working actively with EBRI to develop their businesses; 9 companies have committed (by July 2013) to specific feasibility projects, including some of those named in section 2. The following are specific examples of how the assistance provided is influencing **business developments**:

- Brookside CIC secured funding (£15k) and support from UnLtd to follow up a feasibility study by EBRI that identified the viability of developing a ‘community-scale’ bioenergy plant, based on Aston research, to provide heat, power and cooling to a local Community Centre (July 2013).
- EBRI worked with Environmental Infrastructure Development Company Ltd (EIDC) to form a spin-out company from Aston, Optimus Energy Ltd, (February 2013) and will go to the markets for funding in early 2014. Optimus has formed relationships with Dyteca Ltd and Pearwalk Ltd (specialist equipment designers and manufacturers) under NDA’s entered into in June and March 2013 respectively. Both companies have **committed their own capital** to build “pre-commercial” stage Pyroformers. New employment has already been created for staff, with more envisaged. The impact on Dyteca and Pearwalk, not previously in bioenergy, following introductions through the ERDF project, having seen the benefits of **diversifying into the environmental sector**. *“Working with EBRI has identified the potential for entry into the bioenergy sector with a new range of products and the diversification into a new technology area. This will help with the protection of jobs and possibility of new job creation. Without support from EBRI we would have been unable to*

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*consider diversification into this aspect of green technology” (Dytecna Business Development Manager [5.D]).*

Since 2009, Coca-Cola has benefitted from Bridgwater’s advice, as one of three members of their international Technical Advisory Board [5.F], on producing from biomass their fully sustainable “PlantBottle™”. This role arose from publicity following him receiving the Don Klass award.

Through the InterReg “*Delivering local bioenergy to NW Europe*” project, five “Regional support centres” were established (2011), in France, Germany, Netherlands, UK and Belgium, providing information to companies, investors and regional authorities. Technoeconomic evaluations (based on [3.5, 3.6]) have been provided, for example to the St. Francis Group, who are (July 2013) preparing **regeneration plans** for Tyseley Environmental Enterprise District, Birmingham. The advice has been used to identify locations for bioenergy plant, feedstock supplies and local power users [5.G].

As part of Birmingham’s **environmental planning** to achieve CO<sub>2</sub> reduction of 60% by 2026, a member of EBRI staff has been 50% funded by Birmingham City Council (UK’s most populous city after London) since February 2013. Technoeconomic assessments have identified technical approaches, sites and resources for waste disposal via pyrolysis, simultaneous with power generation. The information was provided in spring 2013 to support preparation of the City’s tender documents for waste disposal for the 25 year period from 2019 [5.H]. In July 2013 West Midlands companies were invited to supply wastes and residues to EBRI, so diverting materials from going directly to landfill or incineration.

A small technical services company, C.A.R.E.Ltd, Belfast, has drawn knowledge since 2008 for customers worldwide [5.I], from Aston’s bioenergy research. The company was formed by Peacocke (Aston PhD 1994, part-time RA until 2008) and Bridgwater was on the company board from its formation until 2011. By July 2013, C.A.R.E. had expanded including by recruiting former bioenergy PhD students for their knowledge of catalysis, biorefinery supply chains and equipment design, so continuing impact from the Aston research through the company.

EBRI has impacted a **Charity** to support rural **Indian communities**, with consequential **social** and **environmental** benefits, and **business opportunities** for Industrial Boilers Ltd, Delhi. Working with the Indian Institute of Technology Ropar, through an RCUK Science Bridge project and more than £500k phased funding from Oglesby Charitable Trust [5.J], a transportable Pyroformer in a standard ISO container, was first operated in the Punjab in June 2013. In the first month to July 2013, this generated oil, gas and biochar from waste biomass from the village so reducing pollution from traditional straw burning in open fields. Fuel-oils produced were used to drive water pumps and generate power, the char used as fertiliser. Power supplied to local communities included to a school never previously lit.

##### 5. Sources to corroborate the impact (indicative maximum of 10 references)

- A. [http://royalsociety.org/uploadedFiles/Royal\\_Society\\_Content/policy/publications/2008/7980.pdf](http://royalsociety.org/uploadedFiles/Royal_Society_Content/policy/publications/2008/7980.pdf) “Sustainable biofuels: prospects and challenges” (2008), Royal Society Policy document 01/08, ISBN 978 0 85403 662, with summary of subsequent debate in international media and public fora compiled by the Royal Society (Head of Projects, Science Policy Centre)
- B. Member, Energy Innovation Policy Team, Department of Energy and Climate Change
- C. IEA Bioenergy Task 34 Pyrolysis (2011), Prof Tony Bridgwater, UK National Team Leader, <http://www.aston-berg.co.uk/Resources/user/Biomass%20pyrolysis%20-%20a%20guide%20to%20UK%20capabilities%20May%202011v2.pdf>
- D. Summary report of business assistance provided as part of review and audit of ERDF project
- E. Environmental Infrastructure Development Company Ltd, Board Member
- F. <http://www.coca-cola.co.uk/environment/plantbottle/introduction-to-plantbottle-packaging.html> Invitation to join Technical Advisory Board with Statement of Work from Coca Cola, Atlanta, Georgia available on request.
- G. Head of Climate Change & Environment , Birmingham City Council
- H. Councillor, Chair of Transport, Connectivity & Sustainability Overview and Scrutiny Committee, Birmingham City Council
- I. C.A.R.E.Ltd, Company Brochure (see examples dated in and after 2008)
- J. Copy of Funding proposal and agreement, Oglesby Charitable Trust